

4.3 Comparisons Between GOES-8 and GOES-11

As previously mentioned, GOES-11 may replace GOES-8 and become the next satellite to provide data for eastern CONUS retrievals. The following sections discuss results of comparisons between GOES-8 and GOES-11 Imager and Sounder from three days of data from the GOES-11 science test performed during July 2000.

4.3.1 Striping Comparison Results

It has been shown that striping appears in IR calibrated images from both the Imager and the Sounder. Because of the striping, averaging of pixels is normally required to produce smoothed surface retrievals. Reduced striping would therefore increase the accuracy and decrease the averaging of retrieval products. The following sections discuss and compare the striping in GOES-8 and GOES-11 Imager and Sounder scenes.

Figures 4.16 and 4.17 present examples of striping in Imager and Sounder scenes respectively. The images seen in Figures 4.16 and 4.17 are enhanced calibrated IR scenes from GOES-8 (left panels) and GOES-11 (right panels) for the longwave IR window channels from the Imager and the Sounder (only channels 7 and 8 from the Sounder are shown). Visual inspection of the images reveals striping in the scenes from both satellites, with GOES-8 tending to exhibit a larger amount of striping. An exception to this general observation is the Imager channel 5 from GOES-11. For several, but not all, of the Imager channel 5 images viewed and analyzed during this research, the GOES-11 striping was seen to be equal to or larger than the GOES-8 striping. This observation correlates to the findings presented by Wack and Candell (1996) that state

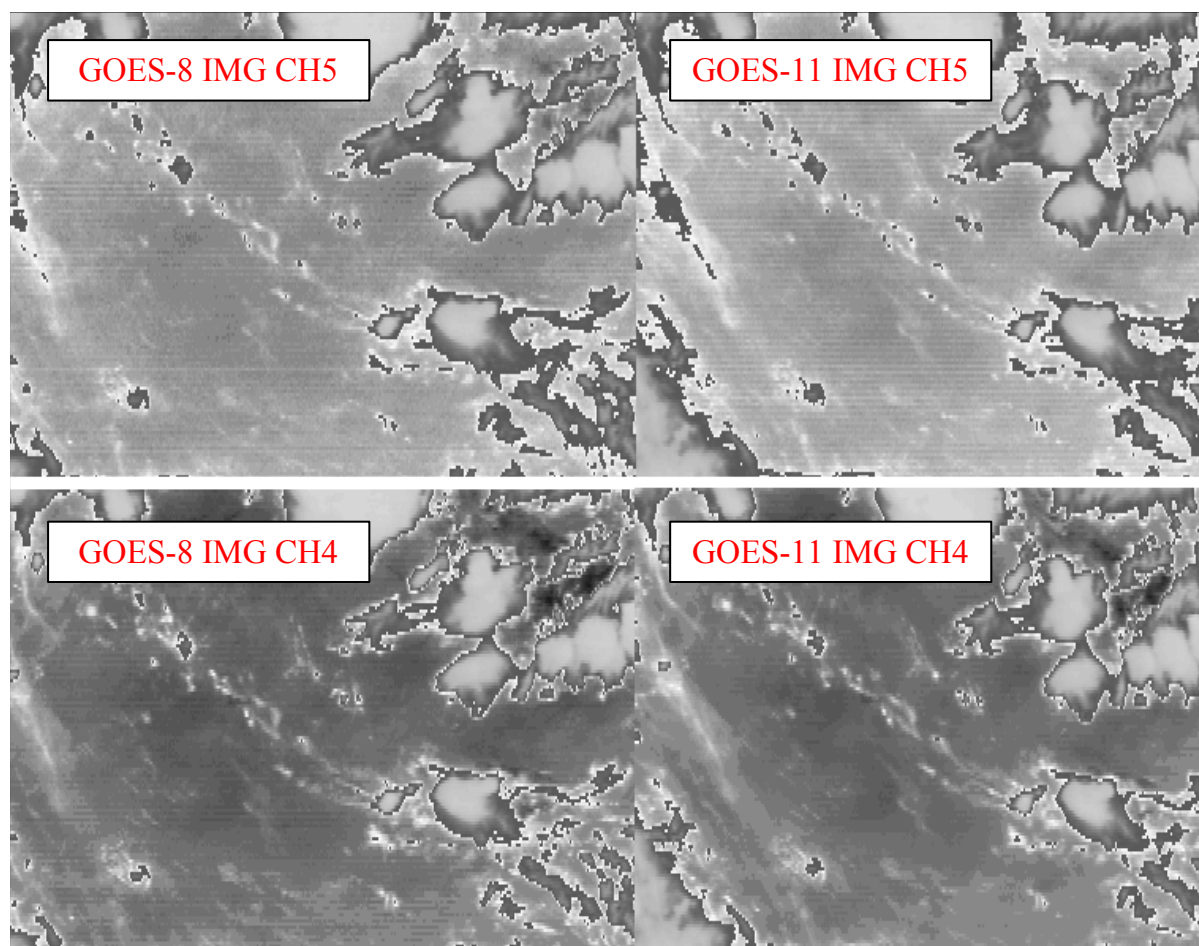


Figure 4.16 Comparison of GOES-8 (left panels) and GOES-11 (right panels) Imager striping from July 27, 2000 at 2145 UTC.

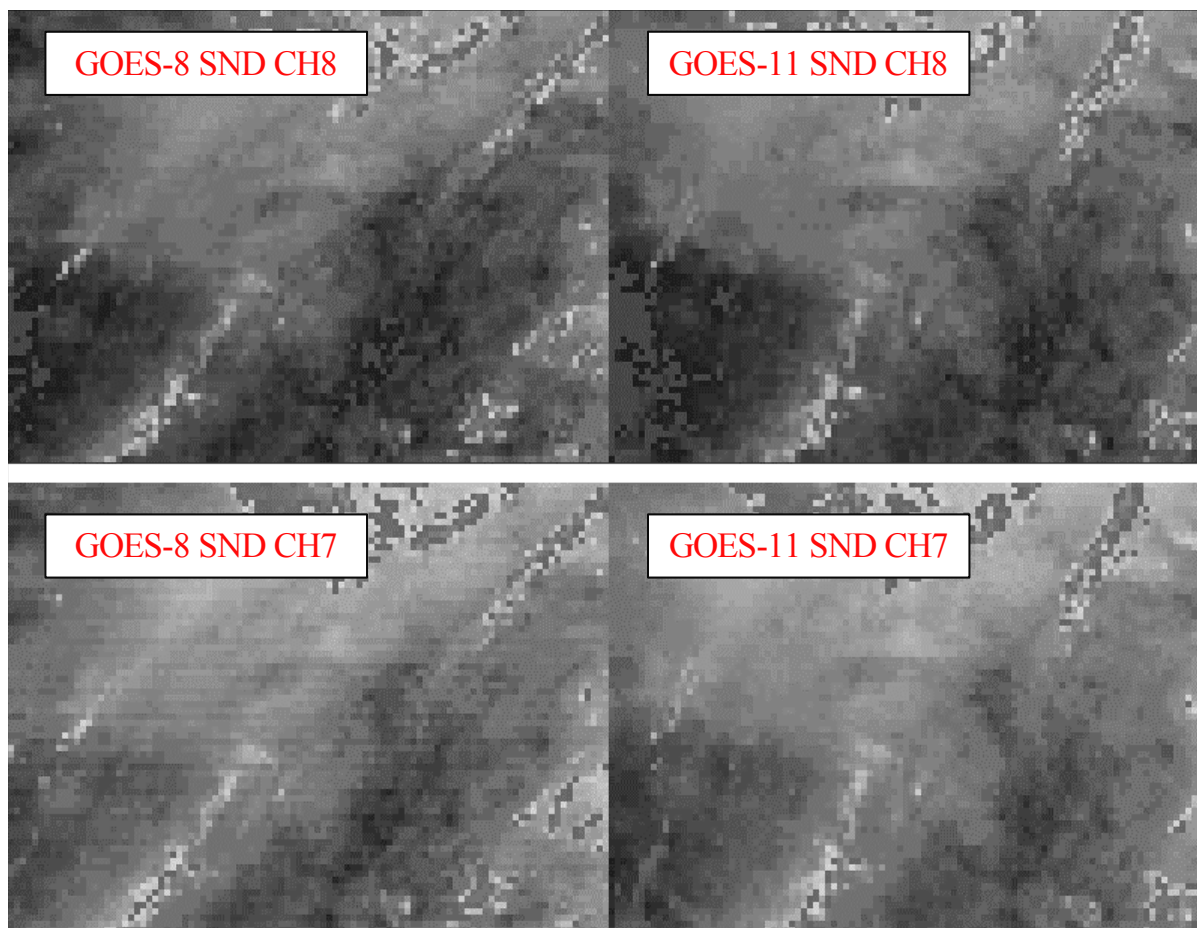


Figure 4.17 Comparison of GOES-8 (left panels) and GOES-11 (right panels) Sounder striping from July 26, 2000 at 1445 UTC.

that the channel 5 striping for GOES-11 can be expected to be similar to GOES-8 striping.

The computed average striping errors for the Imager and the Sounder are presented in Tables 4.1 and 4.2, respectively. Recall that the striping errors are computed as the difference between brightness temperatures from different detectors across a uniform region (see Section 3.4 for more details). The Sounder striping errors are presented as the average of the differences between adjacent lines (error 1), and as the largest difference between adjacent lines (error 2). The average striping errors show improvement for GOES-11, with an average improvement factor of 1.4 from GOES-8 to GOES-11. The smallest improvement of a factor of 1.2, for the Imager channel 5, correlates well to previous observations and Figure 4.16. For the Sounder, channel 8 shows the smallest improvement factor, with a value of 1.3 (for both error computation methods) compared to channel 7 with improvement factors of 1.8 and 1.6 for striping errors 1 and 2, respectively.

The Sounder striping errors cannot be directly compared to the Imager errors because of the difference in striping determination. A visual comparison of the Imager and Sounder striping is also difficult to determine because of the large differences in resolution. Comparing the Imager average striping errors to the Sounder errors computed using the average differences, indicates the striping is similar for the two instruments. However, comparing the Imager striping to the Sounder striping computed using the largest difference between adjacent detectors reveals larger Sounder striping. The largest difference between adjacent lines may be the best indication of striping within an image because this is the striping visually noticed. These results may indicate larger striping

Table 4.1 GOES-8 and GOES-11 Imager average striping errors.

Satellite	Sensor	Channel	Average Striping Error (K)
GOES-8	Imager	4	0.207
GOES-8	Imager	5	0.239
GOES-11	Imager	4	0.130
GOES-11	Imager	5	0.207

Table 4.2 GOES-8 and GOES-11 Sounder average striping errors.

Satellite	Sensor	Channel	Average Striping Error1 (K) (average of the differences)	Average Striping Error2 (K) (largest difference)
GOES-8	Sounder	7	0.250	0.389
GOES-8	Sounder	8	0.177	0.316
GOES-11	Sounder	7	0.138	0.243
GOES-11	Sounder	8	0.137	0.246

exhibited by the Sounder than the Imager, although the Imager striping is computed by averaging over several lines and no averaging is performed during the Sounder computations. Even if the striping in the Sounder images is less than in the Imager images, the Sounder is at a disadvantage because of the coarser resolution. Averaging of Sounder images produces retrievals at low spatial resolutions, and for some applications averaging may not be an option.

Striping is known to increase with decreasing temperature and the Baucom and Weinreb (1996) study presents striping as a function of temperature. In general, the regions sampled for this case study had brightness temperatures in the range 290-300 K. Baucom and Weinreb (1996) study striping in terms of GVAR counts for GOES-8 Imager channel 4 only, and they conclude that the mean GOES-8 Imager channel 4 striping for scenes at 300 K is between 0.11 and 0.18 K. Wack and Candell (1996) estimate GOES-8 Imager channel 4 striping at 0.14 K and channel 5 striping at 0.21 K. Comparisons of these published striping values to those presented in Table 4.1 indicate that the striping values computed during this case study are larger than the published values. However, this case study was for a small sample of regions and for a larger sector size. As the size of the sector increases, the probability of variations between detectors increases because of surface variations. The results from this case study display the same trends as the published results, with the Imager channel 5 having the larger striping value, and the GOES-11 Sounder exhibiting the expected improvement. These preliminary results suggest that striping will still occur in the GOES-11 scenes, but will not be as predominate as the GOES-8 striping. Overall, GOES-11 exhibits an improvement in striping and therefore improvements in the retrievals can be expected.

4.3.2 GOES-8 and GOES-11 ST Retrieval Comparisons

For the three case study days (25, 26, and 27 July 2000), GOES-11 and GOES-8 ST retrievals were produced once an hour for the daytime period 11 – 23 UTC. Most of the Imager retrievals were performed at half past each hour and most of the Sounder retrievals were produced using the 45 minutes past images. The availability of the GOES-11 data restricted the time of the Imager retrievals to be different from the Sounder times for most cases. The GOES-11 retrievals were produced using the identical retrieval methodology as used for GOES-8, but using GOES-11 specific spectral response functions and channel and satellite information adjusted for GOES-11.

Statistics for both satellites were computed over the three domains previously mentioned: CONUS, SE and ocean. Because of the different positions of the two satellites, their viewing angles are different, and therefore the selected domains are not the same. However, the domains from the two satellites cover roughly the same areas, and therefore statistics computed from the domains provide information about the general ST trends exhibited by the Imagers and the Sounders on the two satellites. Retrievals from both satellites are also compared to the ARM site on July 26, 2000.

With only three days of data, these preliminary results can only provide suggestions to the performance of the GOES-11 Imager and Sounder instruments. In addition, changes to the operational calibration procedures may have occurred after the test period. These changes may cause the performance of the satellite during normal operations to differ from what is presented here.

4.3.2.1 GOES-8 and GOES-11 ST Image Comparisons

Visual comparison of the ST retrievals reveals a number of ST trends and noise features. Figure 4.18 shows GOES-8 and GOES-11 Imager and Sounder ST retrievals at single pixel resolution and 3x3 pixel averaged retrievals for five different times during the day. Unlike either the GOES-8 Imager or Sounder retrievals, the GOES-11 Sounder product exhibits a definite diurnal trend of the striping errors. For all three days, the 1145-1345 UTC GOES-11 Sounder ST retrievals exhibit severe striping, as seen in Figures 4.18(a) and (b). As the day progresses, the GOES-11 Sounder striping decreases and, as displayed in Figures 4.18(c) and (d), can be less than the striping seen in the corresponding GOES-8 images. The GOES-11 Sounder striping appears to increase during the 23 UTC hour, as seen in Figure 4.18(e), but does not reach the same level as seen during the early morning hours.

The GOES-11 Imager overall produces the ST images with the least amount of striping and random noise, although the striping does vary significantly with time. The 1545 UTC retrievals (Figure 4.18(c)) show large amounts of striping within the GOES-11 Imager scene, and the smallest amount within the GOES-11 Sounder product. However, there does appear to be a general improvement in noise and striping exhibited by the GOES-11 Imager over GOES-8. The 3x3 pixel averaged GOES-11 Imager retrievals appear to have little noise and striping and retain much of the natural variability of ST across the region. Of the four products, the GOES-11 Imager 3x3 averaged retrievals (at single pixel spacing) produces a ST product with the least amount of noise and striping. This observation correlates to the striping error results presented in the previous section.

(a)

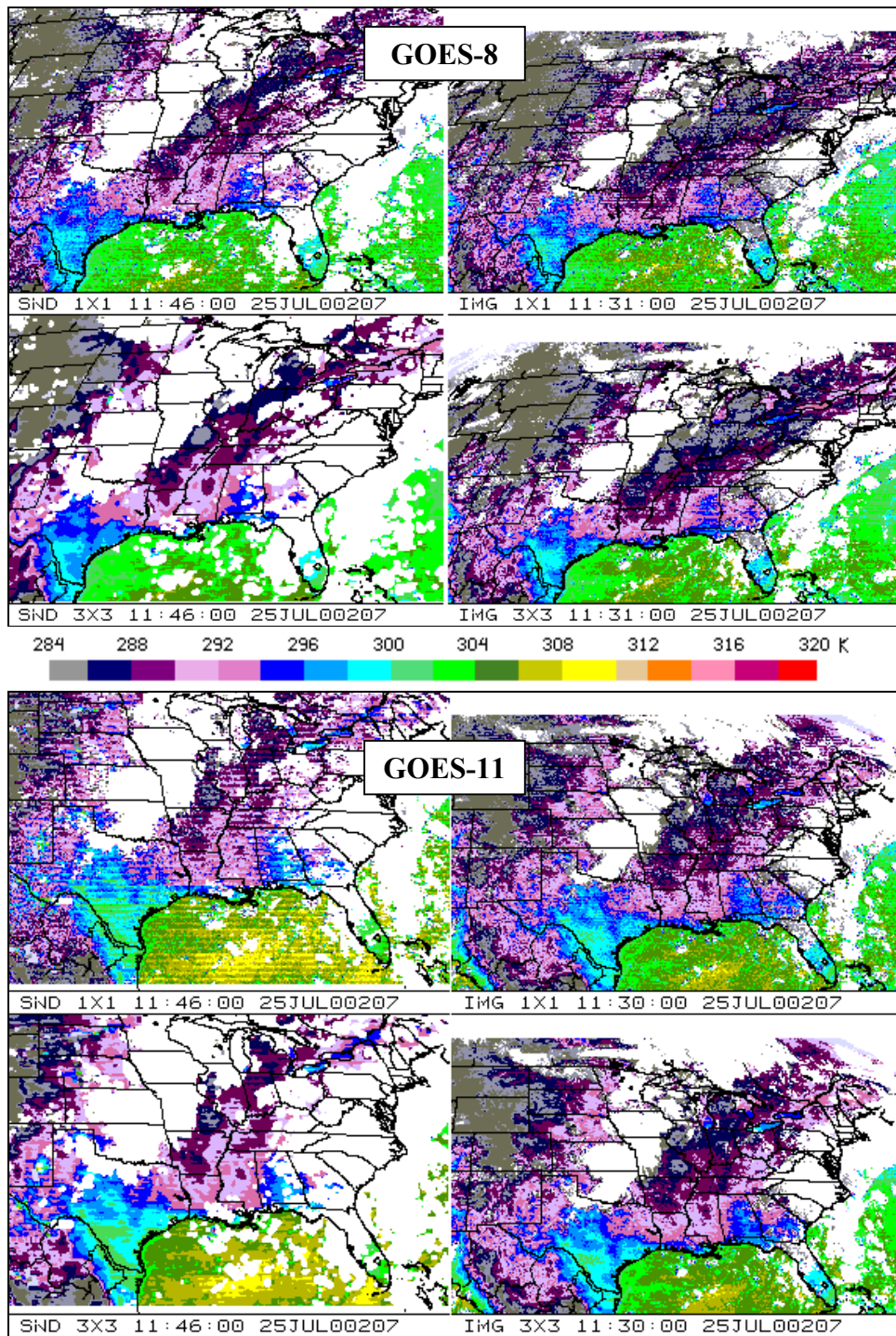


Figure 4.18 GOES-8 and GOES-11 ST retrievals at single pixel resolution and 3x3 pixel averaged resolution at 1130 (Imager) and 1145 (Sounder) UTC on July 25, 2000 (a), 1330 and 1345 UTC on July 26, 2000 (b), 1530 and 1545 UTC July 26, 2000 (c), 2130 and 2145 UTC July 26, 2000 (d), 2330 and 2345 UTC July 26, 2000 (e).

(b)

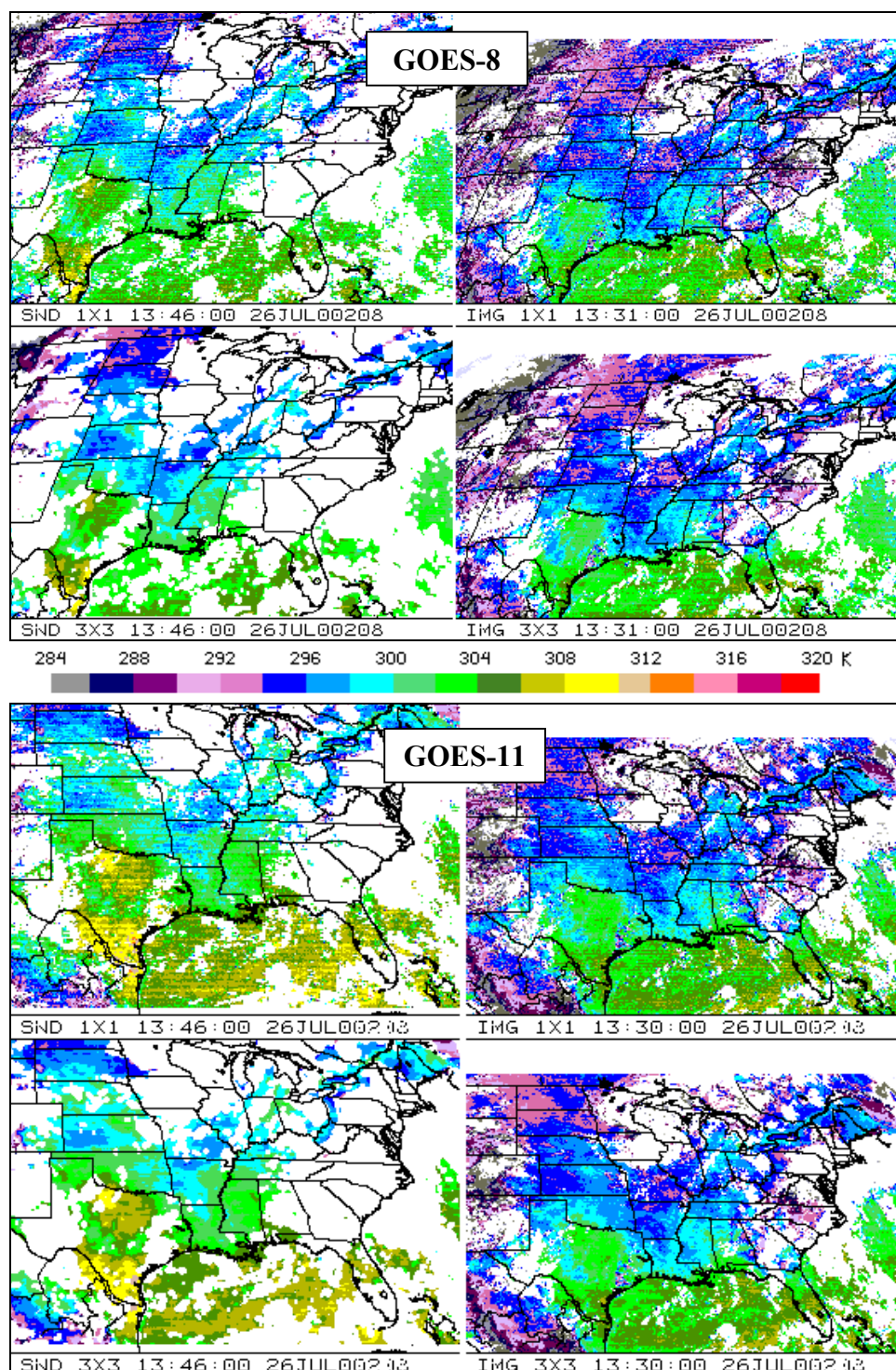


Figure 4.18 (continued).

(c)

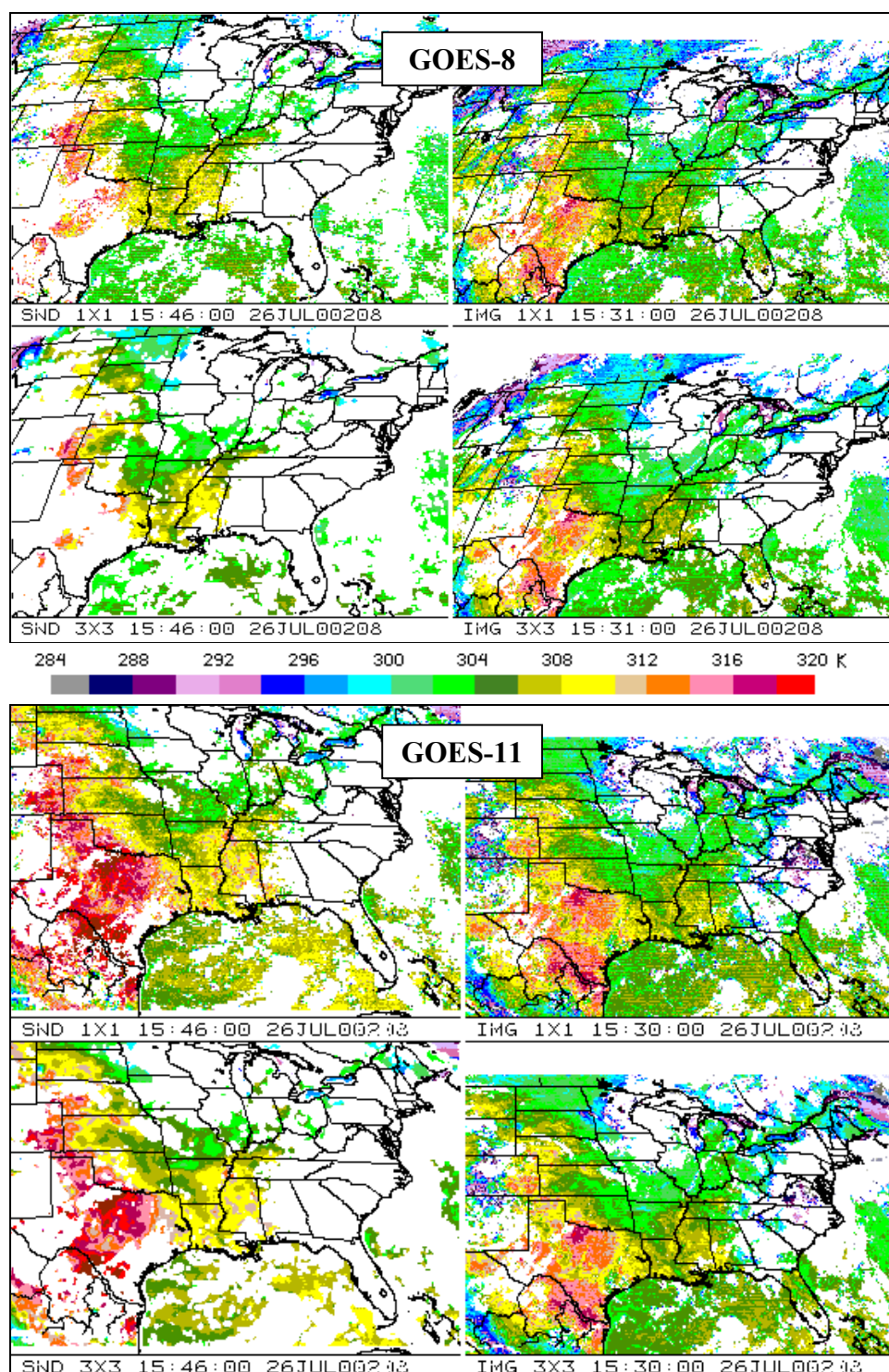


Figure 4.18 (continued).

(d)

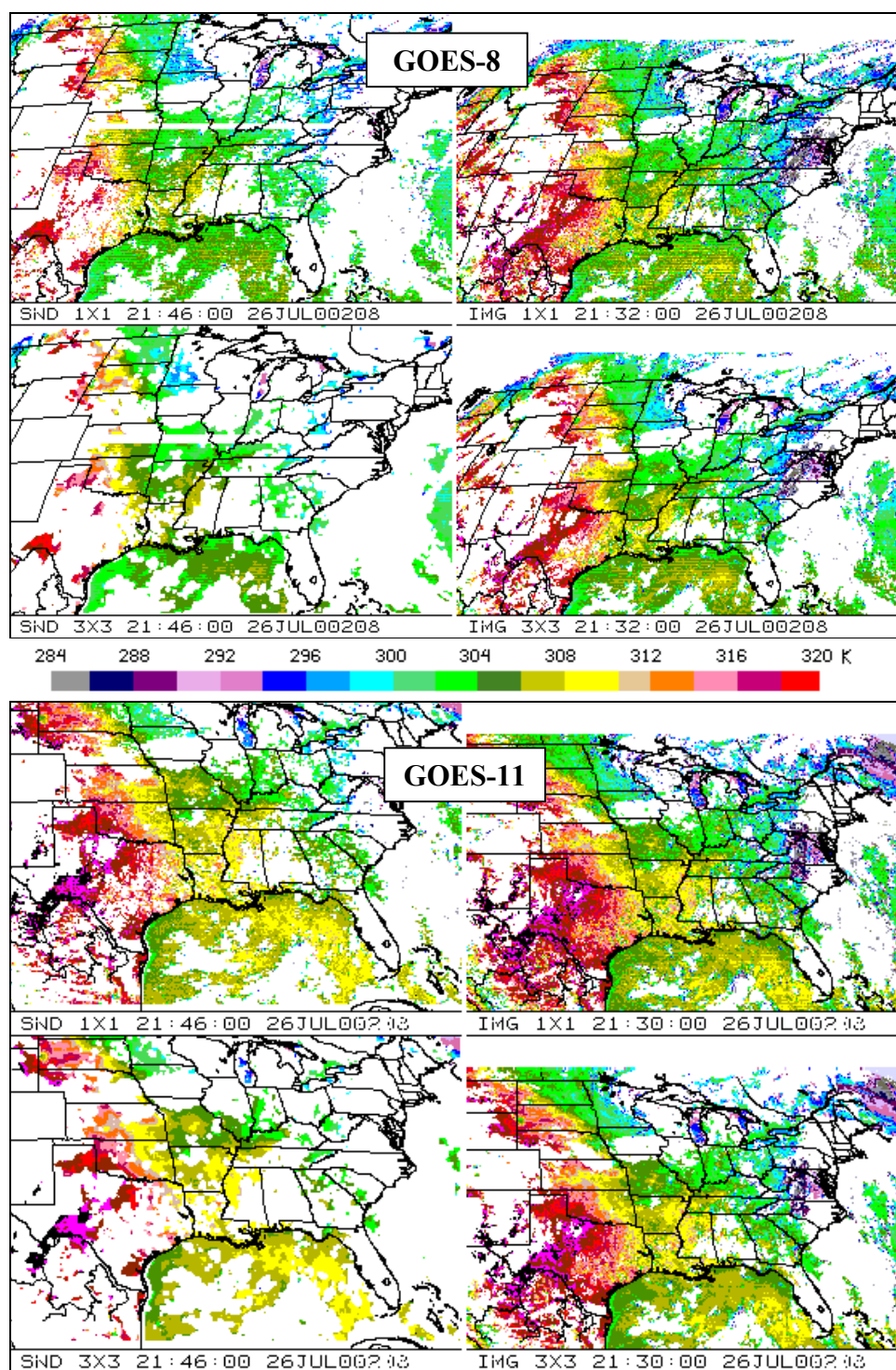


Figure 4.18 (continued).

(e)

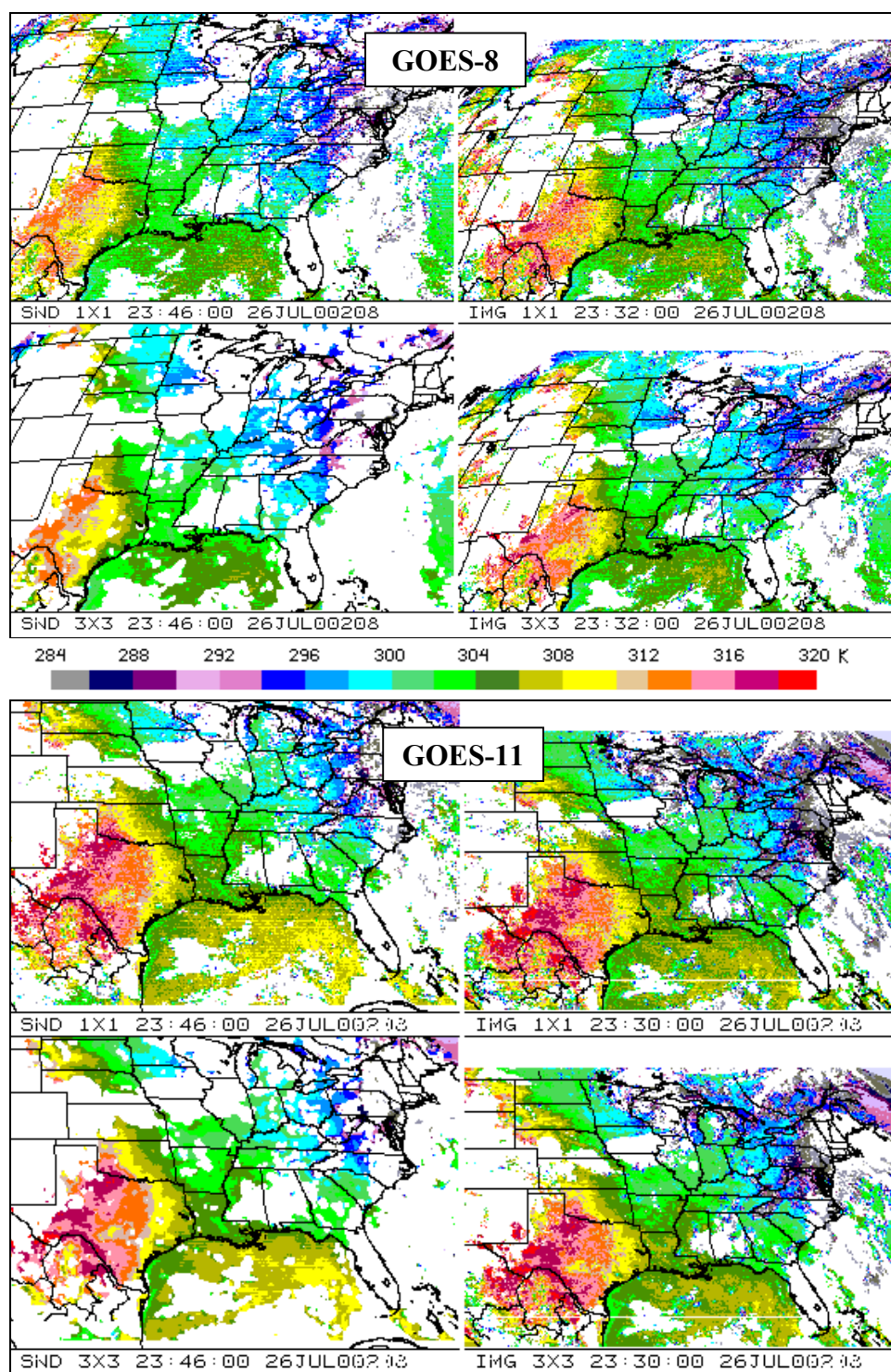


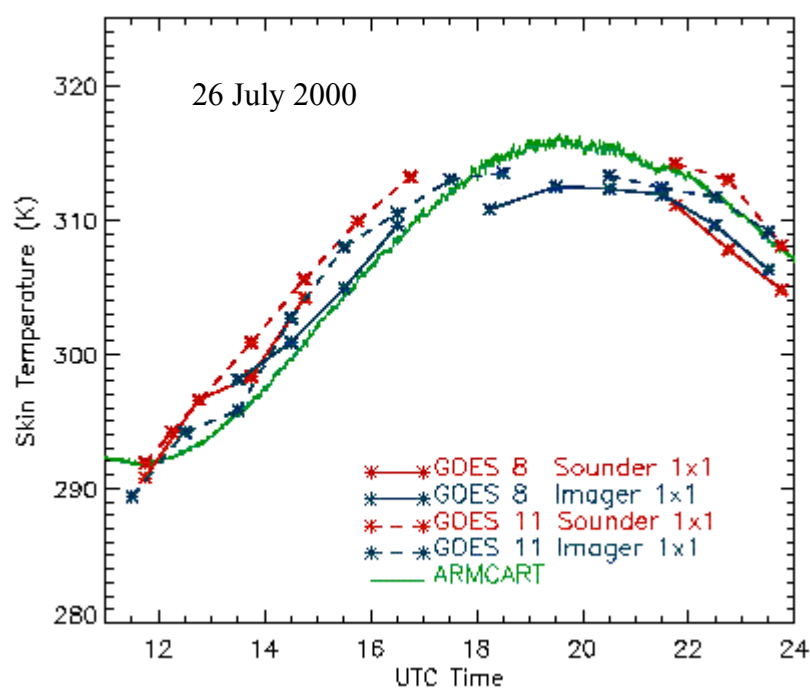
Figure 4.18 (continued).

The striping and noise have been visually assessed, but the magnitude of the ST retrievals also needs to be considered. The ST images shown in Figure 4.18 indicate a warm bias relative to the three other products displayed by the GOES-11 Sounder. This bias appears to be larger during the early morning hours. By the late afternoon, the two GOES-11 products have similar ST patterns and the GOES-8 Sounder appears to have a slight relative cool bias. Again, it appears that the GOES-11 Imager is producing the better product with ST magnitudes between the extremes exhibited by the two Sounder products.

4.3.2.2 GOES-8 and GOES-11 Comparisons to the ARM Ground Truth

Comparisons to the ARM site reinforce the observations made from studying the images of ST. Figures 4.19(a) and (b) show the ST at the ARM site from single pixel resolution retrievals and 3x3 pixel averaged retrievals, respectively, on 26 July 2000. The 1145 and 1245 UTC GOES-8 Imager retrievals were not available. The relative warm bias of the GOES-11 Sounder product is evident during the morning hours, although all three available satellite retrievals during the 11 UTC hour are equal to or cooler than the ARM value. Cloudy conditions persist during the midday hours, as indicated by the lack of Sounder retrievals, and therefore the Imager retrievals can be considered cloud contaminated during this time and thus the cold bias exhibited by the Imager products during the midday hours is explained. All four products are available during the late afternoon hours, and the GOES-8 Sounder provides the coolest values, thus agreeing with the previous observations.

(a)



(b)

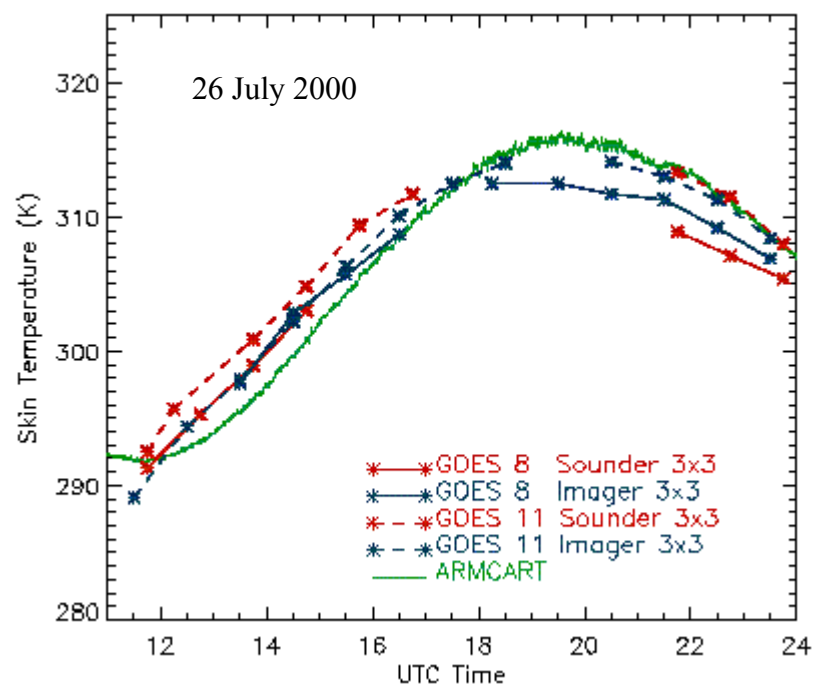


Figure 4.19 Skin temperature retrievals on 26 July 2000, at the ARM site at single pixel resolution (a) and 3x3 pixel averaged resolution (b) from GOES-8 and GOES-11.

All four of the single pixel retrieval products exhibit some variation from the smooth curve produced by the ARM measurements. This variation is most likely striping noise, and therefore can be expected to decline after averaging. Figure 4.19(b) presents the single pixel spacing retrievals derived from 3x3 pixel averaging. The four satellite-derived curves shown in Figure 4.19(b) are smoother than their counterparts shown in Figure 4.19(a). The 3x3 pixel averaged GOES-11 Imager product is the closest to the ARM values in this example.

Notice how all but the GOES-11 Sounder 3x3 retrievals are very similar during the morning hours. The GOES-11 Sounder is significantly warmer than the other retrievals as well as the ground truth values. This is consistent with the GOES-11 Sounder warm bias relative to the other products. Also notice in Figure 4.19(b) how the GOES-8 Sounder is cooler than the other retrievals during the late afternoon hours. Again, this observation corresponds to the previous conclusions drawn from the ST images.

From both the images and the 3x3 averaged point comparisons to ground truth, it appears that the GOES-11 Imager may provide more accurate retrievals with lower striping errors than current products. The previous analysis also reveals that Imager averaged retrievals at single pixel spacing retain much of the natural variation, but reduce most of the striping. The comparisons to the ground truth data suggest the relative warm and cool biases exhibited by the GOES-11 and GOES-8 Sounders, respectively, and how averaging reduces noise in ST products resulting from calibration errors.

4.3.2.3 GOES-8 and GOES-11 Imager and Sounder Inter-Comparisons

The mean temperature and the standard deviation from the mean within selected domains have been computed for both GOES-8 and GOES-11. Statistics were computed for the three case study days for the CONUS, SE, and ocean domains. The following results present an overall diagnosis of the difference between GOES-8 and GOES-11 mean temperature and SD computed values. Statistics were computed using the two different methods. First, the statistics were computed for each instrument using the same number of collocated pixels. Second, mean and SD values were computed for each instrument for all clear pixels, therefore causing the Imager statistics to use a much larger sample size. Since the three case study days during July 2000 had significant cloud cover at certain times and the Imager statistics are influenced by cloud contamination, the results presented here are from statistics computed using method 1. Thus, the Imager cloud contamination effect is much reduced and the statistics reveal general ST trends.

The mean temperatures over the eastern CONUS domain on July 25, 2000 from GOES-8 and GOES-11 are presented in Figure 4.20. The statistics are computed from single pixel retrievals. As previously noted, the GOES-11 Sounder is exhibiting a relative warm bias. The largest differences between the GOES-8 and GOES-11 temperatures are during the early morning hours. During this time the GOES-11 Sounder is approximately 3-4 K warmer than both of the GOES-8 products. The difference between the warmest and coolest products generally decreases throughout the day. The large differences during the early hours suggests that the GOES-11 Sounder is producing a product too warm during these times. As the day progresses, the GOES-11 Sounder warm bias is still apparent, but not as large.

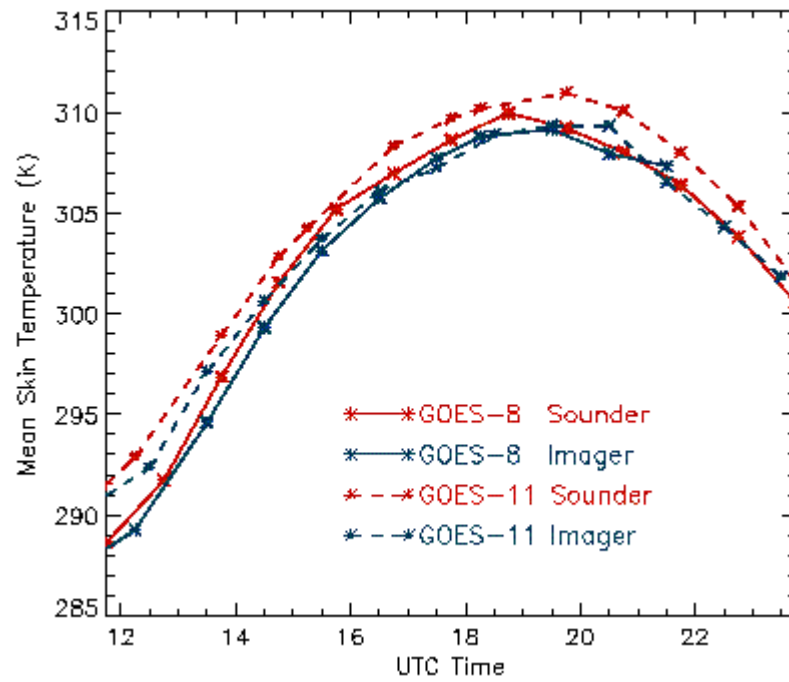


Figure 4.20 GOES-8 and GOES-11 mean skin temperature values computed from single pixel resolution retrievals over the CONUS region on July 25, 2000.

The GOES-8 Imager is the cooler of the four products during the morning hours, but is very close to the GOES-8 Sounder during the early morning hours and close to both the GOES-8 Sounder and the GOES-11 Imager from 17-21 UTC. During the late afternoon hours from 20-23 UTC, the GOES-8 Sounder product becomes the coolest of the four, with differences between the GOES-8 Sounder product and the warmest product (GOES-11 Sounder) ranging between 1-2 K. The relative cool bias of the GOES-8 Sounder suggested by the ARM comparisons and the analysis of the ST images is apparent for this particular day and region as well as other days and regions studied (not shown) during this three day period. However, the GOES-8 Sounder relative cool bias during the latter part of the day is much smaller than the early morning relative warm bias exhibited by the GOES-11 Sounder.

An example of the computed mean temperatures over an ocean region is presented in Figure 4.21. The mean values are computed from 3x3 pixel averaged retrievals on July 27, 2000. Of the three case days provided for these comparisons, July 27 was the only day with clear regions over the oceans. The plot in Figure 4.21 exhibits some of the same patterns revealed by the land statistics, but there are also some differences. The GOES-11 Sounder product again exhibits a relative warm bias throughout the day. The GOES-11 Imager product is also significantly warmer by approximately 1-2 K than the two GOES-8 products throughout the day. The GOES-8 Sounder product does not exhibit the relative cool bias displayed over the land during the late afternoon hours. However, this is a single example and may not be representative of the true relationships between the four products. It is important to notice the GOES-11 warm bias and the similarity between the two GOES-8 products.

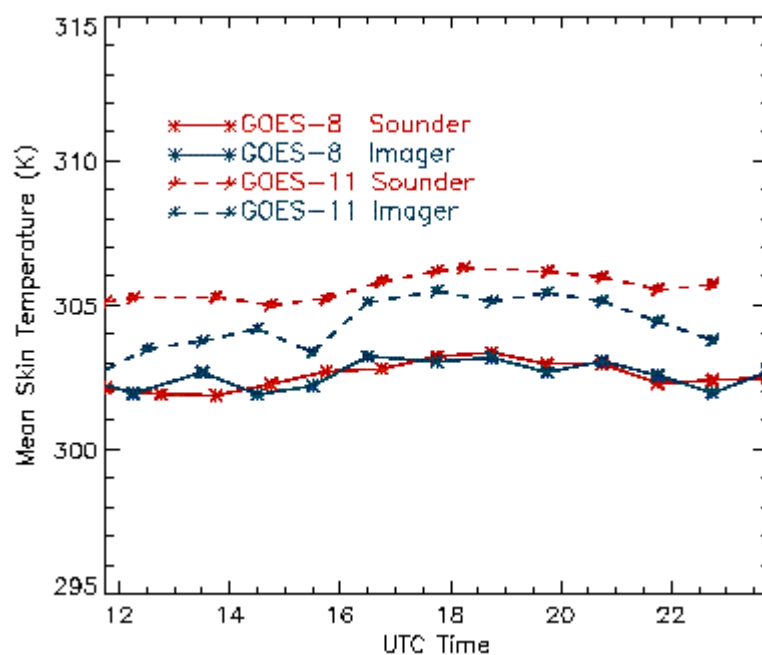


Figure 4.21 GOES-8 and GOES-11 mean skin temperature values from 3x3 pixel averaged retrievals over the ocean domain on July 27, 2000.

In summary, the GOES-11 Imager may be producing the most accurate retrievals with the least amount of striping errors, but the most accurate product is currently unknown. The GOES-11 Imager mean temperature for this case, and others not presented here, generally remains between the minimum and maximum values of the four products. Studying Figure 4.20, it can be seen that the GOES-11 Imager mean values are closer to the GOES-11 Sounder values during the early morning hours than to the GOES-8 values. This may suggest a slight relative warm bias of the GOES-11 Imager product. However, with so little ground truth comparisons, it is unsure which product is the most accurate and when a bias is truly occurring. The biases seen between the GOES-8 and GOES-11 instruments are most likely resulting from the differences between the two satellites including the different viewing angles, different spectral band intervals, and different calibrations.

The SD values for the July 25 CONUS case for single pixel retrievals and 3x3 pixel averaged retrievals are presented in Figures 4.22(a) and (b), respectively. Over the land the GOES-11 Sounder has the highest SD values except during the first few hours of the day. The GOES-11 Imager product has SD values slightly lower than the GOES-11 Sounder product, except during the 2145-2345 UTC period with the single pixel retrievals during which the values are very similar. During the peak heating time, the SD values increase with time as expected because of the varying heating rates of the different surfaces across the region.

There are several explanations for the differences between the SD values for the same instrument but on different satellites. During the early morning and late afternoon hours in particular, the different positions and viewing angles of the satellites may affect

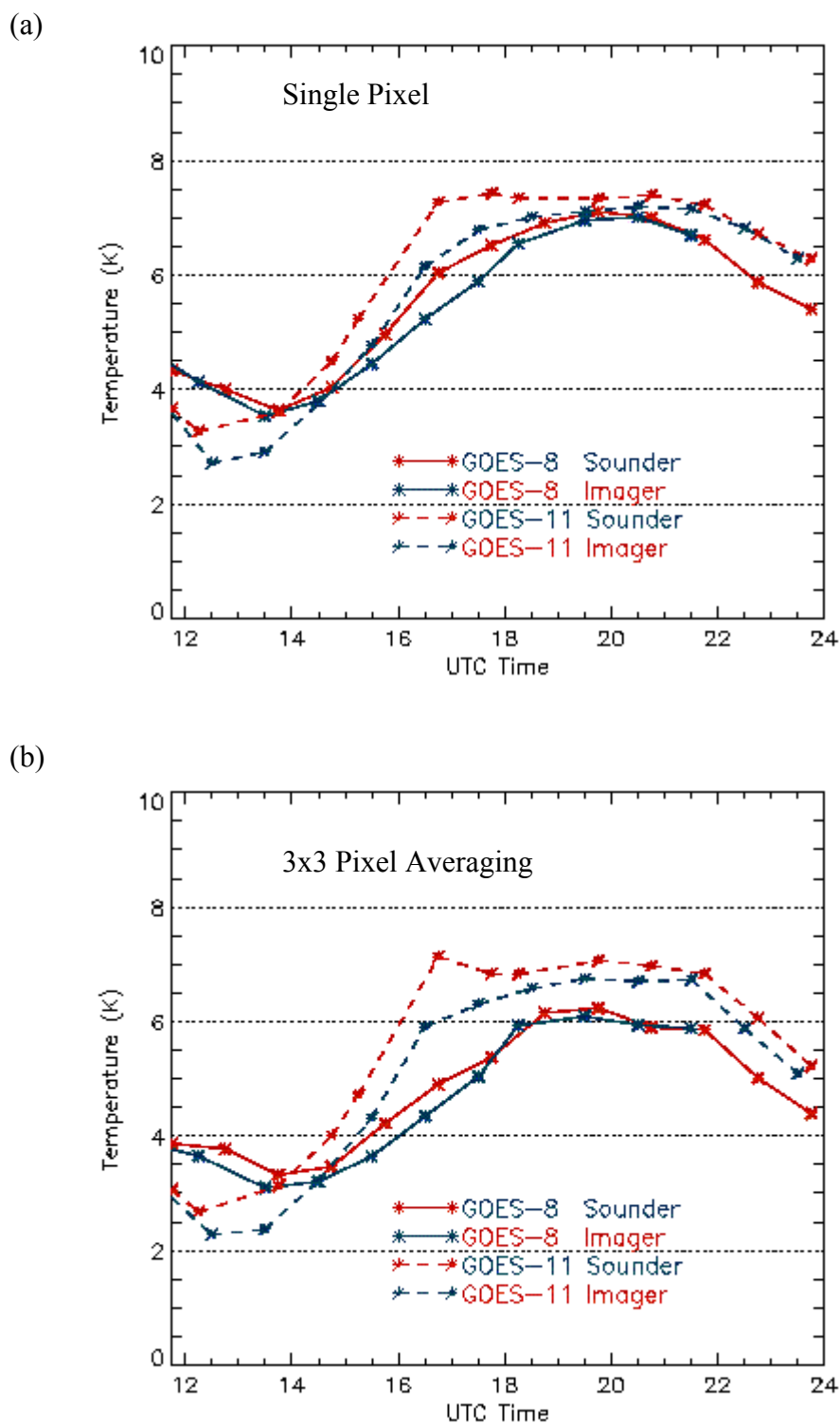


Figure 4.22 GOES-8 and GOES-11 standard deviation values computed from single pixel resolution retrievals (a), and 3x3 pixel averaged retrievals (b) over the CONUS region on July 25, 2000.

the ST retrievals. During periods with low sun angle, such as early morning, the heating of surfaces in hilly and mountainous terrains varies spatially. A bias can be expected from satellite derived STs in mountain areas because the STs are highly dependent on the satellite viewing angle and the sun position (Lipton and Ward 1996). The bias is positive when the satellite and the sun are in the same part of the sky. For the same earth location, the GOES-8 satellite may be receiving a signal from a surface that has been warmed by insolation, whereas the GOES-11 satellite is receiving a signal from the same location but from a surface that has not been heated. This may explain the differences in temperature magnitudes, and may also be an explanation for the differences seen in the SD values.

The viewing angle differences can also help to explain cloud detection differences. The cloud detection method uses a threshold on the $11\ \mu\text{m} - 3.9\ \mu\text{m}$ difference image and is therefore influenced by both the surface emitting temperature and reflected shortwave IR radiation. The amount of emitted IR and reflected IR reaching the two satellites may differ, therefore causing two different cloud masks to be produced. Evaluation of Figure 4.18 does reveal slightly more cloud contaminated ST retrievals (particularly in South Carolina and Georgia) in the GOES-8 Sounder images than in the GOES-11 Sounder images. With more cloud contamination, the SDs can be expected to be greater for the GOES-8 Sounder product. As the day progresses, cloud contamination decreases in all four products, and it can be seen that the GOES-11 Sounder is able to obtain more ST retrievals in western regions of the domain, such as in Texas. With the GOES-11 Sounder obtaining the very warm temperatures in Texas, as well as the cooler temperatures throughout the region, the SD values of the GOES-11 product can be expected to be larger.

With the differences in viewing angle, and thus also variations in the solar heating of the surface being viewed, comparisons between the two satellites cannot provide conclusive results. The cloud masks of the different products have an impact on the statistics, particularly the SD values. By determining statistics using the same number of pixels (collocated) for both the Imager and the Sounder, the combination of the cloud masks of the two products is used, and much of the cloud contamination is removed. However, there are still differences between GOES-8 and GOES-11 in their cloud masks and their regions of assessment.

In summary, the analysis suggests that the GOES-11 Sounder ST product may have a relative warm bias and at times large striping errors. The biases between the four products are most likely resulting from the different viewing angles of the two satellites, the slight differences between the spectral response functions, and variations in the calibration of the IR channels. The GOES-11 Imager produced on average ST retrievals with the least amount of striping and noise, and temperature magnitudes closest to the ARM values. These results were produced during the science test, and hopefully the high striping and noise errors exhibited by both GOES-11 instruments will be reduced when the satellite becomes operational. If these results are indicative of future retrievals, it appears that the Imager will be the logical choice to provide data for ST retrievals and that there will be noticeable improvements over the present ST retrievals. Since GOES-12 will not be able to provide the required data from the Imager, it is hoped that the Sounder instrument on this and future satellites will exhibit definite improvements over the GOES-8 and GOES-11 Sounders so that ST retrievals can continue to improve.